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PRODUCING, STORING, TRANSPORTING,

AND USING KNOWLEDGE

by

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ABSTRACT

The entropy formulas of information theory are not relevant to the cost of obtaining knowledge nor to its value in use. But they are relevant to the expected number of symbols needed for, and hence to the cost of, storing and transmitting messages, especially in long sequences. This is analogous to the cost of storing and transporting material commodities, depending as it does on their weight or volume; while a commodity's production cost, and its value in use, depend on other factors.

It is also worth recalling that to increase the "order" of an aggregate is to decrease the number of its distinct possible states. This decreases the expected number of symbols needed to identify a state, and thus decreases the entropy.

1. Communication Economics

The expected costs and delays involved in communicating (i.e., storing, coding and transmitting) information must be carefully distinguished from the costs and delays in producing information, i.e., in collecting data about the environment by sampling, experimenting, etc.

Moreover, both kinds of expected costs just mentioned must be distinguished from the expected benefits ("information value: the negative of the "Bayesian risk") accruing to the decision-maker who chooses his actions on the basis of messages received. (We assume "utility" to be separable into benefit and cost).

Finally, the delays in producing and communicating information cause two kinds of distinct detriments to the expected benefit: on the one hand, the delayed benefit is discounted over time; on the other (especially in the case of a "Markovian" environment), expected benefit may be diminished when decisions are based on obsolete messages.

In the case of commodities, the distinction between production costs and the costs of storage and transportation, and the distinction between these costs and the value in use, is, of course, familiar to economists and managers. The physical volume or weight of goods in warehouses and in transit is, by and large, the main determinant of the storage and transportation cost. But the cost of producing and the

value of using one unit of weight or volume widely differ from commodity to commodity.

Correspondingly, the <u>number of symbols</u> needed, on the average, to store and transmit a message does, by and large, determine the cost of communication, regardless of how costly was the provision of data, and how beneficial (i.e., important) to the decision-maker are the messages he receives. This average number of symbols is given by the <u>entropy removed</u> ("information amount transmitted"), a parameter of the joint probability distribution of the inputs and outputs of a communication system.

During the last decade, the economic role of the entropy parameter, and its insufficiency as a measure of information value, has been recognized, or partly recognized, by authors in the fields of engineering, logic, and statistics: see, for example, Howard (1966), Carnap (1966), DeGroot (1970). However, many workers in the field, fascinated by the simple properties of the entropy formula as the measure of "information amount," have tried, rather recently, to use it for comparisons of the expected benefits of alternative information systems. In U.S. as well as in U.S.S.R. [Bongard (1963)] and C.S.R. [Perez (1967)], attempts have been made to specify the benefit function (of action and environment) in such a manner as to make the expected benefit from information depend on entropy. How far this approaches economic

reality, is worth investigating.

We stated above that the cost of communication, just like the cost of storing and transporting commodities, is, by and large, independent of the cost of production and the value in use. This is only an approximation. The more valuable a commodity the more will the profit be affected by breakage or leakage, per pound or gallon. Similarly, some distortions of messages reduce the benefit more than others. As suggested by Shannon (1960) and further explored by Jellinek (1963), Pham-Huu-Tri (1968) and others, the code must be adjusted to a "fidelity criterion," which is, in fact, one aspect of the benefit function.

Entropy formulas (in "bits" of information) approximate the expected number of necessary symbols, presupposing efficient encoding of events grouped into long sub-sequences ("blocks"). This is economically relevant only if events follow in quick succession, permitting to neglect the delays and storage costs caused by waiting for the completion of each block. Therefore, many real communication problems will require a cost analysis of alternative codes based on relatively short "blocks"; and channels with equal capacities may call for different codes.

The "transmission rate," i.e., the number of bits transmitted, per unit of time, through a given communication channel is a parameter of the joint probability distribution of the channel's inputs and outputs. H. Theil (1967) has pointed out that since the relative shares of the components of a balance sheet, or of the national product, or of any other total, are non-negative and add up to unity, they can be treated as probabilities. Accordingly, he suggested to use the formula of the transmission rate as a measure of discrepancy between the predicted and the actual relative shares of any composite total. Such a measure can be used, of course, outside of economics as well; and other measures commonly used to express the goodness of prediction might be applied. The comparative economic usefulness of any of those measures would depend on their role in guiding decisions. The suggested measure is related to information economics only in a purely formal way: viz., insofar as the same formula is indeed useful for decisions about the choice of communication channels.

N. Georgescu-Roegen (1966) has given good reasons for an interesting suggestion: to characterize the degree of economic or social order by the negative of entropy. This is analogous to a similar characterization of living organisms [e.g., by Schroedinger (1944)]. I should like to note that,

again, such a degree of order does correspond, presumably, to the number of symbols needed to describe the state of an aggregate such as a society or an organism, or a random collection of particles. The planner, the manager, the "sorter," the "filter" performs a many-to-one mapping or, equivalently, a partitioning (into two equivalence classes in the case of "Maxwell's demon"). The number of possible distinct states and hence the number of symbols needed to identify them is thus diminished.

2. Information Systems as Chains and Networks

The analysis of expected benefits and costs of information, with due regard to transmission fidelity and the cost of communication was carried out in Marschak (1968, 1970) by considering a system of processors, beginning with the processing of events into data, and ending with the processing of decoded messages into decisions. Each processor is characterized by a transition matrix, and by a cost function and a delay function of the input. The assumption (usual in statistical decision theory) of costless and instantaneous decision making need not be made. The user chooses the system maximizing the expected difference between benefit (a function of the sequence of events and decisions) and total cost -- provided utility is additive in these two components.

The system considered so far has been a chain: each processor receives its input from a single predecessor and sends its outputs to a single successor. The following links of the chain were considered: inquiring, storing, encoding, transmitting, decoding, deciding.

More generally, a network rather than a chain of information processors is used in practice. Each processor is a node. It receives its inputs from and sends its outputs to several other nodes. As before, the initial inputs are given by the "environment" and the terminal outputs constitute the "action", but more than one node can receive the environmental inputs, and more than one node represents deciding about the (multidimensional) action of the system.

In particular, an organization as viewed by an "organizer" (characterized by an objective or "utility" function) can be regarded as an information network. This approach was taken in Chapter 8 of Marschak and Radner (1970). The approach should be modified in various ways: by considering the processors as stochastic transformations (instead of using an additive "noise" input); by explicitly introducing, for each processor, a cost and delay function of its inputs; and by regarding "incentives" as costs.

On the other hand, there is a clear relation to the mathematical theory of network flows -- for example, Iri (1969) -- provided the delays, costs and benefits are introduced explicitly.

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